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CHAMBER HAVING IMPROVED PROCESS MONITORING WINDOW

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CHAMBER HAVING IMPROVED PROCESS MONITORING WINDOW

BACKGROUND

The present invention relates to a process chamber and process monitoring window.

In integrated circuit fabrication, layers of semiconductor, dielectric, and conductor materials, such as for example, polysilicon, silicon dioxide, aluminum and copper layers are deposited on a substrate and subsequently processed, for example, by etching with an etchant plasma, to form active devices. The layers are deposited on the substrate in a process chamber by processes such as chemical vapor deposition (CVD), physical vapor deposition (PVD), thermal oxidation, ion implantation and ion diffusion. After deposition, a resist layer of photoresist or hard mask is applied on the deposited layer and patterned by photolithography. Portions of the deposited layers lying between the resist features are etched using RF or microwave energized halogen and other reactive gases to form etched features.

In these fabrication processes, it is often desirable to monitor in-situ the process being performed on the substrate by a process monitoring system. For example, in CVD and PVD processes, it is desirable to stop the deposition process after a desired thickness of a layer is deposited. In etching processes, endpoint detection methods are used to prevent overetching of layers that are being etched. Typical process monitoring methods, include for example, plasma emission analysis, ellipsometry, and interferometry. In plasma emission analysis, an emission spectra of a plasma is measured to determine a change in chemical composition that corresponds to a change in the layer being processed, as for example, taught in U.S. Patent No. 4,328,068 which is

incorporat d herein by reference. In ellipsometry, a polarized light beam is reflected off a layer on the substrate and analyzed to determin a phase shift and a change in magnitude of the reflected light that occurs with changes in the thickness of the layer, as for example disclosed in U.S. Patent Nos. 3,874,797 and 3,824,017, both of which are incorporated herein by reference. In interferometry, a non-polarized light beam is reflected off the layer and analyzed to determine a change in magnitude of the reflected light that occurs due to interference of reflected light components from the top and bottom surfaces of the layer on the substrate, as for example, described in U.S. Patent No. 4,953,982, issued September 4, 1990, which is incorporated herein by reference. These process monitoring methods require a high strength optical transmission signal through the window and also require viewing or signal sampling of relatively large surface area of the substrate.

A typical process monitoring system comprises an optical sensor system for detecting and measuring light emissions or light reflections through a window in a wall of the process chamber. The window is transparent to particular light wavelengths to allow light to be transmitted in and out of the chamber while maintaining a vacuum seal with the chamber. When monitoring a layer on a substrate, the transparent window is positioned in the chamber wall in direct line of sight of the substrate. Process monitoring windows are typically constructed from quartz which is resistant to high temperatures and are sealed to the chamber surface with O-ring seals positioned along their edges.

However, in many deposition and etching processes, a thin cloudy film of residue deposits and byproducts are deposited on the process monitoring window as substrates are being processed in the chamber. The process residues are deposited on the window at rates often in excess of 1 micron in 25 to 50 hours of process operation. The deposited film of process residue changes the properties or intensity of the light transmissions passing through

the window. For example, in plasma emission analysis, th residue deposits selectively filter out particular wavelengths of light from the optical emission spectra of the plasma resulting in errors in process monitoring measurements. In ellipsometry, the residue deposits change the state of polarization of the light beam transmitted or reflected through the window causing erroneous ellipsometric measurements. As another example, in interferometry, the deposits absorb and lower the intensity of the light passing through the window resulting in a lower signal-to-noise ratio.

To avoid these problems, conventional processing monitoring windows are periodically replaced or cleaned to remove the residue deposits formed on the windows. For example, in typical etching processes, after etching a certain number of wafers, or operating cumulatively for about 10 hours, the chamber is opened to the atmosphere and cleaned in a "wet-cleaning" process, in which an operator uses an acid or solvent to scrub off and dissolve the deposits accumulated on the window and chamber walls. After cleaning, the chamber is pumped down for 2 to 3 hours to outgas volatile acid or solvent species, and a series of etching runs are performed on dummy wafers. In the competitive semiconductor industry, the downtime of the chamber during such cleaning processes can substantially reduce process throughput and increase processing costs per substrate. Also, manually performed wet cleaning processes are often hazardous, and the quality of cleaning varies from one session to another.

One approach to solving the residue deposition problem uses a recessed window positioned in a long tube that opens into the chamber. Because the process gas or plasma in the chamber has to travel though the length of the tube before reaching the recessed window, the deposition of process residues on the surface of the recessed window inside the tube is markedly reduced. However, the high aspect ratio (length/diameter) of the

elongated tube makes it difficult to monitor a sufficiently large sampling area inside the chamber, and reduces the total light flux. This limits the accuracy of the process monitoring systems during processing of a batch of substrates or sometimes even for a single substrate. In addition, the elongated tube takes up a large amount of space outside the chamber, which is undesirable in tight clean room spaces, and the tube is also difficult to fit in-between other components of the process chamber.

In another solution, the process monitoring window is selectively heated to prevent deposition of process residue deposits, as described in commonly assigned U.S. Patent No. 5,129,994, to Ebbing et al., issued on July 14, 1992. However, while suitable for certain types of processes, heating does not prevent all forms of residues from condensing and depositing on the window, and in certain processes, heating can actually increase the rate of deposition of process residue on the window.

In yet another approach, photosensitive equipment is used to sample signals of the light emissions or reflections from the chamber/substrate and mathematically manipulate the sampled data to increase the signal to noise ratio of the light signal passing through a cloudy window, as for example, described in U.S. Patent No. 5,738,756 to Liu, issued on April 14, 1998. However, complex mathematical manipulations can delay process response times. In etching processes, even a small time delay can result in undesirable charging or lattice damage of the underlying layers, especially for underlying polysilicon layers. In addition, these processes are not always able to increase the signal to noise ratio by a sufficient amount to provide a discernible signal. If the signal is too small, the fabrication process may never be terminated, and if it is too large, the process may be prematurely terminated.

Th process residues deposited on windows are a particular problem when monitoring tching processes in which etching of a thick overlayer has to be stopped before etching through a relativ ly thin underlayer. For example, the aggressive halogen containing gases etchant gases that are used to etch a relatively thick layer will often uncontrollably etch through or damage any thin underlayers, without an accurate and reliable process monitoring system. This is especially a problem when etching a polysilicon overlayer to expose a thin gate oxide underlayer. After the polysilicon etching process, it is desirable for the remaining thickness of the gate oxide layer to be very close to a nominal and predetermined thickness. As the gate oxide layer becomes thinner, it is more difficult to accurately etch through the polysilicon overlayer without overetching into the gate oxide layer. It is further desirable to stop the etching process on the gate oxide layer without causing charge or lattice damage to underlying silicon by exposed the silicon to the energetic etchant plasma. This type of process control is only possible with a reliable and consistently performing process monitoring system.

Thus it is desirable to have a chamber and process monitoring system that allows monitoring of processing of substrates in the chamber, without excessive signal loss during continued processing of the substrate. It is further desirable to have a process monitoring window that prevents or reduces deposition of process residue on its surfaces and exhibits a low rate of erosion in reactive halogen gases and plasmas. It is also desirable to have a method of monitoring processing of a substrate that provides accurate and repeatable processing results, especially for etching thick overlayers on thin underlayers.

SUMMARY

The present invention provides a process chamber for processing a substrate and monitoring the process being conducted on the substrate with a

high degree of accuracy and repeatability. The chamber comprises a support, a process gas distributor, and an exhaust system. The chamber has a wall comprising a window that allows light to be transmitted therethrough. The window comprises a transparent plate covered by a mask having at least one aperture extending through the mask so that light can be transmitted through the aperture of the mask and the transparent plate to monitor the process being conducted on the substrate. The mask covering the transparent plate reduces deposition of process gas byproducts and other deposits on the window during a process in which a substrate is held on the support and processed by process gas that is distributed by the gas distributor and is exhausted by the exhaust system.

In another aspect, the present invention comprises a process chamber comprising a support having a receiving surface that is adapted to support a substrate. A gas distributor provides process gas in the process chamber to process the substrate and form process gas byproducts. First means are provided for transmitting light into and from the process chamber during processing of a substrate in the process chamber. Second means are provided for masking the first means to reduce deposition of process gas byproducts formed in the process chamber. An exhaust comprising pumps exhaust the process gas and process gas byproducts from the process chamber.

In yet another aspect, the present invention comprises a method of processing a substrate, comprising the steps of placing the substrate in a process zone and maintaining first process conditions in the process chamber to process the substrate, the first process conditions including providing an energized process gas to the process zone. An incident light beam is directed through a window adjacent to the process zone to be incident on the substrate. A measurable intensity of the reflected light beam passing through the window is measured by holding a mask having apertures against the window to reduce

deposition of process gas byproducts on the window. A property of a reflected light beam that is reflected from the substrate is measured. The first process conditions are changed to second process conditions in relation to the measurement of the property of the reflected light beam.

In another aspect, the present invention comprises a method of etching a layer on a substrate substantially without etching or damaging an underlayer. The method comprises the steps of placing the substrate in a process zone and maintaining process conditions in the process zone to etch a layer on the substrate and form process gas byproducts, the process conditions comprising one or more of process gas composition and flow rates, power levels of process gas energizers, process gas pressure, and substrate temperature. An etching endpoint is detected immediately prior to etching through the layer on the substrate by the steps of (1) directing an incident light beam through a window adjacent to the process zone to be incident on the substrate, (2) maintaining a measurable intensity of the reflected light beam through the window by holding a mask having apertures against the window to reduce deposition of process gas byproducts on the window, and (3) measuring a property of a reflected light beam that is reflected from the substrate immediately prior to etching through the layer on the substrate. The process conditions in the chamber are changed in relation to the measurement of the property of the reflected light beam.

In another aspect, the invention is directed to a process chamber having a window in a wall of the process chamber for monitoring the process being conducted on a substrate and a magnetic field source adapted to provide a magnetic flux across the window. The chamber comprises a support, a process gas distributor, and an exhaust system by which a substrate held on the support is processed by the energized process gas, forming process residues

in the proc ss chamber, and the magnetic field source provides magn tic flux across the window to reduce the deposition of process residues on the window.

In yet another aspect, the present invention comprises a process chamber for processing a semiconductor substrate, the process chamber comprising a window and means for maintaining a magnetic flux across the window. The process chamber further comprises a support, a process gas distributor, and an exhaust system. A substrate held on the support is processed by the energized process gas thereby forming process residues in the process chamber. The means for maintaining magnetic flux across the window reduces deposition of process residues on the window.

The present invention also comprises a method of processing a substrate, comprising the steps of placing the substrate in a process chamber and maintaining first process conditions in the process chamber to process the substrate, the first process conditions including providing an energized process gas to the process chamber. Maintaining a magnetic flux across a window in a wall of the process chamber. Directing an incident light beam through the window, and changing the first process conditions are changed to second process conditions in relation to the measurement of the property of the reflected light beam.

In another aspect, the invention is directed to a process chamber having a window in a wall of the process chamber for monitoring the process being conducted on a substrate, and an electrical field source adapted to couple electrical energy to the window. The chamber further comprises a support, a process gas distributor, and an exhaust system. By which a substrate held on the support is processed by the energized process gas, forming process residues in the process chamber, and the electrical energy coupled to the window reduces deposition of the process residues on the window.

In yet another aspect, the present invention comprises a process chamber for processing a semiconductor substrate, the process chamber comprising a window, and means for electrically biasing the window. The process chamber further comprises a support, a process gas distributor, and an exhaust system. By which a substrate held on the support is processed by the energized process gas, forming process residues in the process chamber, and the means for electrically biasing the window reduces deposition of process residues on the window.

In yet another aspect, the present invention comprises a method of processing a substrate, comprising the steps of placing the substrate in a process chamber and maintaining process conditions in the process chamber to process the substrate, the process conditions including providing an energized process gas in the process chamber. Providing a window in a wall of the process chamber, and maintaining an electrical flux across the surface of the window. The electrical flux having an electrical field component that is perpendicular to the plane of the window.

DRAWINGS

These and other features, aspects, and advantages of the present invention will be better understood from the following drawings, description and appended claims, which illustrate examples of the invention. While the description and drawings below illustrate exemplary features of the invention, it is to be understood that each of the features can be used in the invention in general, not merely in the context of the particular drawings, and the invention includes any combination of these features.

Figure 1 is a schematic sectional view of an embodiment of a process chamber according to the present invention showing a window and overlying mask;

Figure 2 is a schematic sectional view of another process chamber according to the present invention;

Figure 3a is a schematic sectional view of yet another process chamber having a tilted window and overlying mask according to the present invention;

Figure 3b is a schematic top view of one embodiment of a mask according to the present invention;

Figure 4a is a schematic side view of another embodiment of a window and overlying mask;

Figure 4b is a schematic top view of the window and overlying mask of Figure 4a;

Figure 5 is a graph showing the net deposition of process residue as a function of the aspect ratio of different sized apertures in a test mask;

Figure 6a is a partial schematic side view of another process chamber embodiment showing a magnetic field source for maintaining a magnetic flux across the window;

Figure 6b is a top view of the window of Figure 6a showing a permanent magnet having a pair of facing magnetic poles with an aperture therebetween;

Figure 6c is a schematic top view of the window of Figure 6b showing the magnetic flux lines across the aperture;

Figure 6d is a schematic top view of window and a magnetic field source comprising a plurality of magnetic poles around an aperture;

Figure 7 is a schematic sectional view of another process chamber embodiment with a window and an electrical field source comprising an electrode behind the window;

Figure 8a is a partial schematic side view of another process chamber embodiment with a window and an electrode behind the window;

Figure 8b is a schematic top view of the electrode of Figure 8a showing an array of eddy current reducing slots;

Figure 8c is a schematic top view of another embodiment of the electrode and eddy current slots; and

Figure 8d is a schematic top view of another embodiment of the electrode and eddy current slots.

DESCRIPTION

The semiconductor processing apparatus **20** and process monitoring system **25** of the present invention is useful for fabricating integrated circuits on a semiconductor substrate **30**. The processing apparatus **20**, as schematically illustrated in Figure 1, comprises a process chamber **35** having a process zone **40** for processing the substrate **30**, and a support **45** for supporting the substrate **30** in the process zone **40**. An electrostatic chuck **50**

holds th substrate **30** on the support **45** during processing of the substrate **30**. The process zone **40** surrounds the substrate **30** and typically comprises a volume of about 10,000 to about 50,000 cm^3. The process chamber **35** can comprise a flat rectangular shaped ceiling **55**, or a ceiling which is arcuate, conical, dome-shaped, or multi-radius dome-shaped. Preferably, the ceiling **55** is dome-shaped to enable a gas energizer **60** to uniformly couple power across the entire volume of the process zone **40** thereby providing a more uniform density of energized gaseous species across the substrate surface than a flat ceiling **55**.

Process gas is introduced into the process chamber **35** through a gas distribution system **65** that includes a process gas source **70**, a gas flow control valve **75**, and a process gas distributor **80**. The gas distributor **80** can comprise gas outlets located at or around the periphery of the substrate **30** (as shown), or a showerhead mounted on the ceiling **55** of the process chamber **35** with outlets therein (not shown). Spent process gas and etchant byproducts are exhausted from the process chamber **35** through an exhaust system **85** (typically including vacuum pumps **90** such as a 1000 liter/sec roughing pump and a 1000 to 2000 liter/sec turbomolecular pump) capable of achieving a minimum pressure of about 10^{-3} mTorr in the process chamber **35**. A throttle valve **95** is provided in the exhaust system **85** to control the flow of spent process gas and the pressure of process gas in the process chamber **35**.

The gas energizer **60** couples electromagnetic energy to the process gas to form energized gaseous species. In the embodiment shown in Figure 1, the gas energizer **60** comprises an inductor antenna **100** encircling the process chamber **35** to energize the process gas directly in the process zone **40** through inductive coupling by applying an RF current to the inductor antenna **100**. Alternatively, the process gas is energized by capacitive coupling by applying an RF voltage to a gas energizer **60** comprising process electrodes

formed by the support **45** and the ceiling **55** of the process chamber **35**. In the process chamber **35** of Figure 1, the ceiling **55** comprises a semiconducting material to function both as a process electrode for capacitively coupling RF energy into the process chamber **35**, and as a window for inductively coupling RF energy into the process chamber **35**. The frequency of the RF energy applied to the inductor antenna **100**, or process electrodes **45,55**, is typically from about 50 KHz to about 60 MHz, and more typically about 13.56 MHz. Preferably, the RF voltage applied to the process electrodes **45,55** by an electrode power supply **102** is at a bias power level of from about 1 to about 500 Watts; and the RF current applied to the inductor antenna **100** by a coil power supply **104** is at a source power level of from about 500 to about 2000 Watts.

Figure 2 shows an alternative embodiment of the processing apparatus **20** in which the process gas is energized or activated by the gas energizer **60** in a remote chamber **105**, such as a tube or cylinder adjacent to the process chamber **35**. By "remote" it is meant that the center of the remote chamber **105** is at a fixed upstream distance from the center of the process chamber **35**. The remote chamber **105** comprises a gas energizer **60** that couples microwaves or other frequencies of electromagnetic energy from a suitable source into a remote zone **110**, to activate process gas introduced into the remote chamber **105**. A suitable microwave source comprises a microwave applicator **115**, a microwave tuning assembly **120**, and a magnetron microwave generator **125** and is typically operated at a power level of from about 200 to about 3000 Watts, and at a frequency of from about 800 MHz to about 3000 MHz.

In yet another embodiment of the processing apparatus **20**, the uniformity and density of ions in the energized process gas can be enhanced using electron cyclotron resonance or a magnetic field generator **127**, such as

permanent magnets or electromagnetic coils **129**. For example, a MxP+ OXIDE ETCH chamber, commercially available from Applied Materials Inc., Santa Clara, California, and generally described in commonly assigned U.S. Patent No. 4,842,683, issued June 27, 1989, which is incorporated herein by reference. Referring to Figure 3a, process gas is introduced into the process zone **40** and energized by an electric field generated by applying a RF power to the support **45** and the ceiling **55** or sidewalls of the process chamber **35**. Preferably, the magnetic field comprises a rotating magnetic field with the axis of the field rotating parallel to the plane of the substrate **30**. The magnetic field in the process chamber **35** should be sufficiently strong to increase the density of the ions formed in the energized process gas, and sufficiently uniform to reduce charge-up damage to features formed on the substrate **30** such as CMOS gates. Generally, the magnetic field as measured on a surface of the substrate **30** is less than about 500 Gauss, more typically from about 10 to about 100 Gauss, and most typically from about 10 Gauss to about 30 Gauss.

The process monitoring system **25** monitors the progress of a process being performed in the process chamber **35** thorough a window **130** in the process chamber ceiling **55** or a wall that is transparent to light that is emitted from, or directed into, the process chamber **35**. The process monitoring system **25** is particularly useful for monitoring the progress of a layer being etched, and to prevent damaging an underlying layer on the substrate **30**. Suitable process monitoring systems **25** include detectors based on optical emission, ellipsometry, and interferometry. Optical emission detectors detect changes in the spectral lines of light spectra emitted by species in the energized process gas to detect changes in chemistry that would indicate the beginning of etching of the underlying layer. Ellipsometers project a light beam at an acute angle to the surface of the substrate **30** and detect a phase shift between portions of the light beam reflected off the top and bottom surfaces of a transparent film on the substrate **30**. An interferometer also reflects a beam of

light off the top and the bottom surface of a transparent film on the substrate **30**. However, an interferometer determines the thickness of the film on the substrate **30**, by measuring the magnitude of constructive or destructive interference between the reflected light beams, and does not need to project the incident light beam at an acute angle relative to the surface of the substrate **30**. In fact, typically the interferometer directs the light beam at nearly a right angle relative to the surface of the substrate **30**, i.e., at an angle of close to 90°. Unlike an optical emission detector, the interferometer detector can be used to detect and stop a semiconductor etching process before reaching an underlying layer below the layer being etched. Also, because the light beam is directed at nearly a right angle, the interferometer can be used for etching features having high aspect ratios, which would block the low angle beam of the ellipsometer. Thus it is generally preferred to use an interferometer system to detect the endpoint of an etch process performed in the process chamber **35**.

Referring to Figures 4a and 4b, a window **130** according to the present invention comprises a transparent plate **135** and an overlying mask **140** having at least one aperture **145** extending therethrough. The mask **140** covers the surface of the transparent plate **135** facing the inside of the process chamber **35** so that light can be transmitted through the transparent plate **135** and the aperture **145** of the mask **140** to monitor the process being conducted on the substrate **30**. The mask **140** covering the transparent plate **135** serves to reduce deposition of process residue, byproducts, and other deposits on the window **130**, thereby allowing accurate and reproducible monitoring of processes conducted on the substrate **30**. The light transmitted through the window **130** comprises plasma spectra for plasma emission analysis or light reflected from the substrate **30** that is used for process monitoring systems **25** based on interferometry or ellipsometry principles. The window **130** is shaped, sized, and located to allow an incident light beam **148a** transmitted therethrough to be incident on the substrate **30** at an angle that is sufficiently

large to provide a near vertical incidence of the light near the center of the substrate **30**. Generally, the window **130** can comprise any shap including circular, oval, or polygonal shape.

The transparent plate **135** of the window is made of solid transparent material that is transparent to selected frequencies of electromagnetic radiation used in the process monitoring system **25**. Preferably, the transparent plate **135** is transparent to ultraviolet, visible, and infrared light from a light source **150** used to provide the incident light beam **148a** for the endpoint detection system. To prevent attenuation of the incident light beam **148a** by scattering, both surfaces of the transparent plate **135** are polished smooth with a peak-to-peak RMS roughness (i.e., the vertical distance between the peaks and valleys of the roughness on the polished crystal face) that is sufficiently small to allow light to be transmitted therethrough. Preferably, the peak-to-peak RMS roughness of the transparent plate **135** is less than about 1 μm, and more preferably less than about 0.1 μm. The surface of the transparent plate **135** can be polished smooth by any suitable means, for example, by flame polishing or conventional lapping and/or ablating methods.

The transparent plate **135** is made of a ceramic monocrystalline material that is a single crystal material or one that comprises a few (typically 10 or fewer) large crystals that are oriented in the same crystallographic direction, and is transparent to particular wavelengths of light or visible radiation. Preferably, the monocrystalline material comprises a ceramic, such as for example, one or more of Al_2O_3, Si, SiO_2, TiO_2, ZrO_2, or mixtures and compounds thereof. The monocrystalline ceramic material is selected to exhibit high corrosion resistance in a particular plasma or other process environment. In a preferred embodiment, the transparent plate **135** comprises polished sapphire, which is a monocrystalline form of alumina that exhibits high chemical and erosion resistance in halogen plasma environments, especially fluorine

containing environments. Monocrystalline sapphire also has a high melting temperature that allows use of the window **130** at temperatures exceeding 1000°C, and preferably in excess of 2000°C.

In one embodiment, the transparent plate **135** is tilted at a small angle relative to the plane of a surface substrate **30**, so that light reflected from the transparent plate **135** is not reflected back into the process monitoring system **25**, thereby allowing greater signal gain in process monitoring. A suitable angle of tilt is at least about 2 degrees, and more preferably, from about 2 to about 15 degrees. For example, Figure 3a shows a tilted transparent plate **135** that is angled about 3 degrees relative to the plane of the substrate **30**. The tilted plate **135** is angled by raising one side or edge of the transparent plate **135** higher than the opposing side/edge of the transparent plate by providing a raised step **152** below an edge of the transparent plate **135**. The step is sized depending on the angle of elevation or tilt that is desired and is typically from about 0.5 to about 5 mm depending on the diameter of the transparent plate **135**.

The mask **140** covering the transparent plate **135** serves to reduce deposition of process gas byproducts formed in the process chamber **35** on the transparent plate **135**. The mask **140** is made of a material that is resistant to erosion by the process gas and/or the plasma formed from the process gas. Preferably, the mask **140** is made from a plasma resistant material comprising one or more of Al_2O_3, SiO_2, AlN, BN, Si, SiC, Si_3N_4, TiO_2, or ZrO_2. Referring to Figure 4b, one embodiment of the mask comprises a thick disc of aluminum oxide that is shaped to cover substantially the entire exposed portion of the transparent plate **135** of the window. Preferably, when the transparent plate **135** comprises a disc, the mask **140** comprises a right cylinder that is shaped and sized to cover the surface of the disc. More preferably, the mask **140** comprises disc having a raised central portion **153** with a surrounding

annular lip **154**. The thickness of the raised central disc portion is preferably from about 0.5 mm to about 500 mm. The diameter of the raised central portion **153** of the mask is from about 50 mm to about 200 mm. The thickness of the annular lip **154** is from about 0.5 mm to about 10 mm, and a smooth rounded edge forms the transition between the raised central disc and the annular lip **154**.

The mask **140** comprises at least one aperture **145** that allows a sufficient intensity of light to pass through the aperture to operate the process monitoring system **25**, and that controls the access of energized process gas species to the transparent plate **135** of the window **130**. The cross-sectional area of the aperture **145** sufficiently large to allow a sufficiently large amount of light flux to ingress and egress from the process chamber **35**. The aperture **145** can be cylindrical, or polygonal in shape, including triangular, hexagonal, square, and rectangular, of which hexagonal is preferred since it enables a plurality of apertures **145** to be more closely spaced allowing improved transmission of light into and out of the process chamber **35**. The aspect ratio of the aperture **145** controls the access of energized process gas species to the transparent plate **135** of the window **130**. Preferably, the aspect ratio of the aperture **145** is from about 0.25:1 to about 12:1.

In one embodiment, the aperture **145** is shaped and sized to limit or reduce access of the process gas to the transparent plate **135** and thereby prevent deposition of process gas byproducts and other deposits on the transparent plate **135**. This accomplished by making the aspect ratio of the aperture **145** (which is the ratio of the aperture's height to its diameter/width) sufficiently large or high to limit access of the neutral flux of process gas, and therefore access of the volatilized process gas byproducts that condense to form process residues, into the aperture **145** and onto the underlying

transparent plate **135** of the window **130**. Preferably, the aspect ratio is from about 1:1 to about 12:1, and more preferably from about 3:1 to about 7.5:1.

In another embodiment, as illustrated in Figure 3b, the shape and size of the aperture **145** in the mask **140** is selected to reduce the accumulation of process residue on the underlying transparent plate **135** of the window **130** by a different mechanism. In this version, the aspect ratio of the aperture **145** is sufficiently small to allow ions of the energetic process gas to enter the aperture and etch away the process residues formed on a sidewall of the aperture **145** and/or on the surface of the transparent plate **135**. The aperture **145** in this embodiment generally has a larger sized diameter or width relative to its height to provide a relatively low aspect ratio. The low aspect ratio preferentially filters out energetic plasma species to allow a higher percentage of highly directional and energetic plasma species to enter into the aperture **145** and sputter-etch away the process residue deposited on the sidewalls of the aperture **145** and on the surface of the transparent plate **135**. A suitable aspect ratio is from about 0.25:1 to about 3:1, and more preferably from about 0.5:1 to about 2:1.

The mask **140** can also comprise a plurality of apertures **145**, and more preferably, an array of apertures as already described. Preferably, the total area of the aperture **145** is sufficiently large to transmit both an incident light beam **148a** and a reflected light beam **148b** or the desired level or intensity of plasma spectra flux for plasma emission analysis. Preferably, for process monitoring systems **25** comprising interferometry or ellipsometry systems, the total area of the transparent plate **135** exposed by the aperture **145** is sized to enable the incident light beams **148a** to be moved or scanned across the surface of the substrate **30** to find a particular feature, such as a via or a deep narrow trench, or a suitably flat and/or transparent point at which to make a process endpoint measurement. For example, in a process chamber **35** used for

processing 300 mm substrates, the area of the aperture **145** should be preferably from about 200 to about 2000 mm^2 (0.3 to about 3 in^2) and more preferably from about 400 about 600 mm^2 (0.6 to about 0.9 in^2).

In another embodiment, shown in Figures 4a and 4b, the mask **140** can also comprise a plurality of apertures **145** that are spaced apart from one another. For example, the mask can comprise an array of apertures **145** sized and arranged to have a total opening area that provides a sufficient intensity of light to pass through to operate the process monitoring system **25**. The actual size, number or arrangement of apertures **145** depends upon the particular process chamber **35**, the substrate diameter, the process, and the type of process monitoring system **25**. In one embodiment which is particularly useful for interferometric optical systems, the mask **140** comprises apertures **145** having an opening dimension, such as a diameter or a width of about 0.1 to about 50 mm, and a height of about 0.5 to about 500 nm. The array preferably consists of from about 3 to about 800 apertures **145**, and more preferably from about 7 to about 200 apertures **145**, as shown in Figure 4b. The apertures **145** are spaced apart from one another by a distance of about 0.25 to about 15 mm. Also, as shown in Figure 3b, the array can comprise different sized apertures **145**, for example, first apertures **145a** in the central portion that have an average diameter of about 3.5 to 5 mm, and second apertures **145b** at its circumferential edge having a diameter of 2 to 3 mm.

It has been discovered that the mask **140** overlying the window **130** substantially reduces deposition of process residue on the transparent plate **135** of the window **130**. For example, the overlying mask **140** and window **130** has been found to reduce deposition of etchant residue in polysilicon etching processes down to about 3 to about 10 Å/hr, which is about 100 times lower than that occurring on conventional unprotected windows. In addition, the mask **140** protects the window **130** from erosion by highly chemically

reactive process gases, and has been found to extend the lifetime of the window **130**. Also, the "footprint" (occupied area of clean room) of a process chamber **35** comprising a window **130** having a mask **140** according to the present invention is much smaller than that of other process chambers **35** having conventional clean-window systems.

The process chamber **35** and window **130** of the present invention allows use of process monitoring methods such as interferometry, ellipsometry, or plasma emission analysis. The reduced residue deposition on the process monitoring window **130** increases the signal to noise ratio of the process monitoring systems **25** to levels that provide accurate and reliable readings even after processing a large number of substrates **30**. The accuracy of these measurement techniques provides the necessary process control for the deposition and etching of thinner films on the substrate **30**, to provide faster and higher operating frequency integrated circuits. In addition, because the process chamber **35** does not have to be frequently opened to clean the surface of the window **130**, the process chamber efficiency and the substrate throughput is also enhanced.

Operation of a process chamber and process monitoring system **25** using a window **130** according to the present invention will now be described. As described above, the process monitoring system **25** can be an interferometry or ellipsometry system that compares a property of the reflected light beam **148b**, such as its intensity and/or phase angle, to known or stored characteristic values to calculate the endpoint of the etching process. Preferably, the process monitoring system **25** comprises a computer controller **155** that adjusts the process conditions in the process chamber **35**. Upon detection of the process endpoint, the computer controller **155** changes the first process conditions to second process conditions to change the rate of etching of the layer on the substrate **30** before the entire layer is etched through or to

stop the etching process. For example, the etch rate can be reduced by changing the composition of the process gas to remove aggressive etchant gases, the RF power coupled to the process gas can be lowered, or the substrate temperature can be lowered.

A suitable computer controller **155** comprises a computer program code product that operates the process chamber **35**, and comprises one or more central processor units (CPUs) interconnected to a memory system with peripheral control components, such as for example, a PENTIUM microprocessor, commercially available from Intel Corporation, Santa Clara, California. The CPUs of the computer controller **155** can also comprise ASIC (application specific integrated circuits) that operate a particular component of the process chamber **35**. The interface between an operator and the computer controller **155** can comprise a CRT monitor and a light pen (not shown), or other devices, such as a keyboard, mouse or pointing communication device.

The light source **150** comprises a monochromatic or polychromatic light source **150** that generates an incident light beam **148a** having an intensity sufficiently high to provide a reflected light beam **148b** that is reflected from a layer on the substrate **30**, when the layer has a suitable thickness, with a measurable intensity. In one version, the light source **150** provides polychromatic light, such as a Hg-Cd lamp, which generates an emission spectrum of light in wavelengths from about 200 to about 600 nanometers. The polychromatic light source **150** can be filtered to provide an incident light beam having selected frequencies, or particular emission spectra wavelengths can be used, or color filters (not show) can be placed in front of a light detector **160** for detecting the reflected light beam **148b** to filter out all undesirable wavelengths except the desired wavelength of light, prior to measuring the intensity of the reflected light beam **148b** entering the light detector **160**. The

light source **150** can also comprise a monochromatic light source **150** that provides a selected wavelength of light, for example, a He-Ne or ND-YAG laser.

One or more convex focusing lenses **165** are used to focus the incident light beam **148a** from the light source **150** as a beam spot or collimated beam on the substrate surface and to focus the reflected light beam **148a** back on an active surface of the light detector **160**. The size or area of the beam spot should be sufficiently large to compensate for variations in surface topography of the substrate **30** to enable etching of high aspect ratio features having small openings, such as vias or deep narrow trenches. The area of the reflected light beam **148a** should be sufficiently large to activate a large portion of the active light detecting surface of the light detector **160**.

Optionally, a light beam positioner **170** is used to move the incident light beam **148a** across the substrate surface to locate a suitable portion of the layer being etched on which to "park" the beam spot to monitor etching process. The light beam positioner **170** comprises one or more primary mirrors **175** that rotate at small angles to deflect the incident light beam **148a** from the light source **150** onto different positions of the substrate surface, and to intercept the reflected light beam **148b** and focus it on the light detector **160**. In another embodiment, the light beam positioner **170** is used to scan the light beam in a raster pattern across the substrate surface during processing. In this version, the light beam positioner **170** comprises a scanning assembly consisting of a movable stage (not shown) upon which the light source **150**, focusing assembly, collecting lens, and detector are mounted. The movable stage can be moved through set intervals by a drive mechanism, such as a stepper motor, move the beam spot across the substrate surface.

The light detector **160** comprises an electronic component having a light sensitive surface, such as a photovoltaic cell, photodiode, or

phototransistor, which provides a signal in response to the intensity of the reflected light beam **148b** that is incident on the light sensitive surface. The signal can be in the form of a change in the level of a current passing through an electrical component or a change in a voltage applied across an electrical component. Preferably, the reflected light beam **148b** undergoes constructive and/or destructive interference which increases or decreases the intensity of the reflected light beam **148b** as the thickness of the film or trench on the substrate **30** increases or decreases, and the light detector **160** provides an electrical output signal in relation to the measured intensity of the reflected light beam **148b**. The computer system receives the signal from the light detector **160**, compares the signal to a stored value or waveform, and changes process conditions in the process chamber **35** according to programmed guidelines in relation to the signal.

An example of a substrate processing method according to the present invention will now be described, with reference to an exemplary etching process, in which a polysilicon overlayer on a gate oxide (silicon dioxide) underlayer, is etched without etching or damaging the underlayer. Initially, a reflectance thickness measuring machine is used to accurately determine the initial thickness of the layer to be etched on the substrate **30**, such as a model UV1050 available from KLA-TENCOR, Santa Clara, California. The actual layer thickness is useful to estimate the overall operation time of the etching process and/or to calculate the thickness of the layer that should be etched to provide a predetermined thickness of the layer that remains on the substrate **30** after the etching process.

The substrate **30** is transferred by a robot arm (not shown) from a load-lock transfer chamber **180** through a slit valve and into the process zone **40** of the process chamber **35**. The substrate **30** is placed on the support **45** where it is held by the electrostatic chuck **50**. Optionally, a heat transfer gas is

supplied through holes **185** in the surface of the electrostatic chuck **50** to control the temperature of the substrate **30**. Thereafter, the process conditions in the process chamber **35** are set to process the particular layer on the substrate **30** and to form process gas byproducts, the process conditions comprising one or more of process gas composition and flow rates, power levels of gas energizers **60**, gas pressure, and substrate temperature. The process can also be performed in multiple stages, for example, each stage having different process conditions. For example, in an etching process, one or more compositions of an energized process gas comprising etchant gas for etching the substrate **30** are provided in the process chamber **35**. Suitable etchant gases for etching layers on the substrate **30**, include for example, HCl, BCl_3, HBr, Br_2, Cl_2, CCl_4, $SiCl_4$, SF_6, F, NF_3, HF, CF_3, CF_4, CH_3F, CHF_3, $C_2H_2F_2$, $C_2H_4F_6$, C_2F_6, C_3F_8, C_4F_8, C_2HF_5, C_4F_{10}, CF_2Cl_2, $CFCl_3$, O_2, N_2, He, and mixtures thereof. The process chamber **35** is typically maintained at a pressure ranging from about 0.1 to about 400 mTorr. The etchant gas composition is selected to provide high etch rates and/or high etching selectivity ratios for etching the overlayer relative to the underlayer. When multiple layers are being sequential etched, first, second, third, etchant gas compositions can be sequentially introduced into the process chamber **35** to etch each particular layer.

The process gas is energized and maintained at first process conditions suitable for etching the substrate **30**. Referring to Figure 1, an energized process gas is provided in the process zone **40** by inductively and/or capacitively coupling energy into the process zone **40** using the gas energizer **60**, or by applying microwaves to an etchant gas in the remote zone **110** of the remote chamber **105**, as shown in Figure 2. By energized process gas, it is meant that the process gas is activated or energized so that one or more of dissociated species, non-dissociated species, ionic species, and/or neutral species are excited to higher energy states in which they are more chemically reactive. Preferably, the process gas is energized by applying an RF source

current to the inductor antenna **100** encircling the process chamber **35** or by applying an RF bias voltage to the process electrodes. The etchant gas ionizes in the applied electric field to form ions and neutrals that etch the layer on the substrate **30** to form volatile gaseous species that are exhausted from the process chamber **35**.

The process monitoring system **25** is used to precisely change process conditions, after a given thickness of the layer on the substrate **30** is processed. In etching processes, the process monitoring system **25** can be used to change the process gas composition to provide particular etching rates or etching selectivity ratios. For example, the process monitoring system **25** can be used to stop the etching process after a first highly aggressive etching step, which provides high etch rates due to the presence of the fluorinated gas in the etchant gas, to determine the starting point for a second and less reactive etching step, which uses a process gas that is absent the fluorinated gas to etch the remaining dielectric layer at a slower etch rate to obtain more controlled etching. The process monitoring system **25** is used to detect the time at which almost all of the silicon layer is etched so that the first process conditions can be changed to less aggressive or second process conditions, or vice versa, to obtain the desired change in etching rate, etching selectivity ratio, or a change in any other property of the etching process, for example, higher/lower etching rates, or etching of underlying layers having a different composition.

Generally, in the method of the present invention, the incident light beam **148a** is transmitted through the energized process gas in the process zone **40** of the process chamber **35**, to be incident on the layers covering the substrate **30** while the layers are being etched. These experiments were conducted using a light source **150** consisting of a Hg-Cd lamp. A light beam from this light source **150** is directed through the window **130** to be incident on

the substrate **30** at a near vertical angle, to provide a beam spot having a size sufficiently large to cover one or more of the features being etched on the substrate **30**. It is preferred for the incident light beam **148a** to consist of substantially only non-polarized light, because polarized light is preferentially absorbed by deposition of a thin residue on the process window **130**.

When the thickness of the layer is sufficiently low (after etching for a period of time) a property of the reflected light beam **148b** that reflects off both the top and bottom surfaces of the layer on the substrate **30** is measured. Changes in the measured property, such as the intensity or phase of the reflected light beam, is recorded over time to form a measured waveform pattern. The measured waveform pattern is compared to a stored waveform pattern, and when the two signals are substantially the same, the endpoint of the etching process is reached. At that time, the first process conditions are changed to second process conditions in relation to the measurement of the property of the reflected light beam. For example, first process conditions are changed to second process conditions to stop the etching process, to change the rate of etching of the layer on the substrate **30**, or to change its etching selectivity ratio relative to the underlayer, before the entire layer is etched through.

The measured intensity of the reflected light beam **148b** can also be plotted over time to obtain a measured waveform pattern, and the measured waveform pattern is compared to a predetermined characteristic waveform pattern to determine an endpoint of the etching process that occurs when the two waveforms are the same or substantially identical to one another, as described in commonly assigned U.S. Patent Application No. 09/062,520, by Grimbergen et al, filed on April 17, 1998, which is incorporated herein by reference. In this method, a computer controller **155** plots the electrical output signal of the intensity of the reflected light beam **148b** over time to provide a

waveform spectra having numerous waveform patterns corresponding to the varying intensity of the reflected light beam **148b**. The computer controller **155** calculates a real-time waveform spectra of light reflected from a thickness of a layer being processed on the substrate **30** and compares the waveform of the measured intensity to a stored characteristic waveform pattern and adjusts process conditions in the process chamber **35** when the two waveforms have substantially the same shape and form. The computer program determines the completion of a stage of processing of the layer when the measured waveform pattern comprises a repeatable waveform oscillation that occurs immediately before a terminal peak or dip in a reflected waveform pattern, the terminal peak or dip corresponding to completion of processing of the layer. The computer program can also include program code to calculate in real time, the thickness of the layer being etched that remains on the substrate **30** and accordingly adjust the process conditions in the process chamber **35**. The computer program can also count the number of maxima and minima peaks in the intensity of the reflected light beam and, after a predetermined number of peaks are reached, alter process conditions in the process chamber **35**, according to programmed guidelines.

In another aspect of the present invention, an in-situ or dry cleaning process can be performed in conjunction with the process monitoring method of the present invention to enhance the operation of the process chamber **35**. In this method, a first layer on a substrate **30** is etched in a first stage of the etching process by a process gas comprising a composition of etchant gas that provides a high etching rate and a process chamber cleaning gas that removes the residue deposits and process gas byproducts as they are formed on the walls of the process chamber **35**. Because the cleaning gas is an extremely aggressive fluorine containing gas which will quickly etch through a thin underlying gate oxide layer, the process monitoring system **25** is used to detect the process endpoint and change the composition of the process gas to

remove the cleaning gas immediately prior to etching through the first layer. The cleaning gas in the first stage of the process cleans the process chamber **35** without requiring stopping etching in between processing of batches of substrates **30** to perform wet cleaning processes. In a preferred embodiment, the etchant gas comprises one or more of Cl_2, N_2, O_2, HBr, or He-O_2; and the cleaning gas comprises inorganic non-hydrocarbon containing fluorinated gas such as one or more of NF_3, CF_4, or SF_6. Preferably, the volumetric flow ratio of cleaning gas to etchant gas is selected to remove substantially all residue deposits and process gas byproducts from process chamber surfaces upon completion of the first stage. More preferably, the volumetric flow ratio of cleaning gas to etchant gas is selected to remove substantially all residue deposits and process gas byproducts formed during processing of at least 2000 substrates **30** in the process chamber **35**, without performing a separate cleaning step for cleaning the process chamber **35**. A suitable volumetric flow ratio of cleaning gas to etchant gas is from about 1:20 to about 1:1, and more preferably from about 1:10 to about 2:3, and most preferably about 2:3. It has been discovered that at these volumetric flow ratios substantially all the etchant residue on the process chamber surfaces is removed without eroding the process chamber surfaces. In addition, it has been unexpectedly discovered that the process chamber surfaces are cleaned and conditioned by the etchant and cleaning gas combination step, without requiring a separate process chamber conditioning or seasoning step. Suitable cleaning gas compositions are provided in aforementioned U.S. Patent Application No. 09/062,520.

EXAMPLES

The following examples illustrate use of a process chamber **35** having a window **130** and mask **140** according to the present invention. In these examples, a series of 200 mm silicon substrates **30** having a 2500 Å polysilicon layer, a 45 Å silicon dioxide layer, and a 2000 Å patterned resist

layer, were etched. A multi-stage process was used for etching the polysilicon layer on a substrate **30**. In a first or main etching stage, an energized process gas comprising 50 sccm CF_4 and 40 sccm SF_6 is provided in the process chamber **35** to etch through most of the thickness of the polysilicon layer exposed through openings in the resist layer. The process gas is energized by applying a source power of 750 watts to the inductor antenna **100**, and a bias power of 90 watts to the process electrodes **45, 55**. The process chamber pressure is maintained from about 2 to about 3 mTorr. After the process endpoint is detected using a process monitoring system **25**, the main etch stage was stopped and remaining polysilicon removed in a second or over-etch stage substantially without damaging the underlying silicon dioxide layer. In the overetch stage, a second energized process gas comprising 60 sccm of SF_6 is introduced in the process chamber **35**, and energized by a source power of 600 watts and a bias power of 1 watt. The process chamber **35** is maintained at a pressure of about 10 mTorr.

The process was performed in a process chamber **35** having a window **130** comprising masks **140** of varied thicknesses and having apertures **145** of varying number, diameter, and aspect ratios to determine their effectiveness in reducing accumulation of process residue on the transparent plate **135**. In general, the mask **140** comprised an aluminum oxide disc having a raised central portion **153** surrounded by a thin annular lip **154** as shown in Figure 4b. The mask **140** was positioned about 0.038" from the transparent plate **135**, and small slides (not shown) of an etch resistant material such as sapphire or Kapton® were positioned between the mask **140** and transparent plate **135** to shield a portion of the transparent plate **135** exposed through each aperture **145**. The total time the process chamber **35** was in operation was recorded and after a specified times the window **130** was removed and the thickness of process residue deposited on and/or the amount of material removed from the transparent plate **135** was measured using a stylus step

height measuring device such as a DekTak, or an Alpha-step. The transmission of light through the transparent plate **135** was also measured using a light source of known intensity and a light detector capable of accurately measuring the intensity of the transmitted light.

Example 1:

In a first example, the mask **140** had a raised central portion **153** 19 mm (0.75") thick, and comprised a hexagonal pattern of 19 apertures, each 3.8 mm (0.15") wide and each having an aspect ratio of 5:1. This example demonstrates that an array of apertures **145** having a small diameter and a large aspect ratio reduce deposition of process residue on the transparent plate **135** of the window **130**. After etching in the chamber for 80 minutes, the window **130** was disassembled, the sapphire slide removed, and the transparent plate **135** scanned using a stylus step height measurement instrument to determine the accumulation of process residue and the etching of the transparent plate **135**. Because the high aspect ratio of the small apertures **145** excluded all the residue forming plasma species from reaching the transparent plate **135**, there was no discernable etching of the transparent plate **135**. Moreover, the thickness of process residue on the transparent plate **135** was below the limit that could be measured, i.e., less than 600 Å. The change in transmission of light through the transparent plate **135** was also found to be below detectable limits, i.e., less than 1%.

Example 2:

In this example, the mask **140** comprised a raised central portion **153** 0.75" thick and circular apertures **145** having varying diameters from 0.1" to 1". After the process chamber **35** was operated for 80 minutes, the mask **140** was found to significantly reduce deposition on the transparent plate **135**

as compared to conventional windows. The window **130** was replaced, uncleaned, and examined again after an additional 18 and 25 hours of operation. The accumulation of residue deposits, and etching of the transparent plate **135** for the various sized apertures **145** after 25 hours of operation is summarized in Table I.

TABLE I

HOLE SIZE (inches)	ASPECT RATIO	CENTER THICKNESS (angstroms)	EDGE ETCH (angstroms)	PROJECTED TRANSMISSION OF 245 NM AT 150 HOURS
1"	0.75	4000 to 5000	-3000 to -6000 Å at 5mm	High at edge; moderate in center
0.5"	1.5	0	-2500 Å	High
0.25"	3	550 to 650	-250 Å at 0.5mm	Moderate
0.2"	3.75	410 to 500	None	Moderate to High
0.15"	5	170 to 200	None	High
0.1"	7.5	70 to 100	None	High

Referring to the graph of Figure 5 it is seen that as the diameter of the aperture **145** becomes smaller and the aspect ratio increases, the flow of neutral plasma species flux that contribute to deposition of the process residue deposits into the aperture **145** is gradually reduced and can be entirely excluded from reaching the transparent plate **135**. The net deposition of process residue on the transparent plate **135** initially increases as the diameter of the apertures **145** are reduced from 0.5" to 0.25", and thereafter decreases as the aperture **145** continues to become smaller. In contrast, as aperture size increases above 0.5" and the aspect ratio is reduced from 2:1 to 0.75:1, deposition controls at

the center of the aperture **145**, while etching dominates near the sidewall or edge of the aperture **145**. In contrast, for apertures **145** having aspect ratios of from about 1 to about 2, there is negative net deposition rate across substantially the entire width of the aperture, arising from allowing entry of substantially only energetic plasma species into the aperture **145**.

Magnetic Field Confinement

In another embodiment of the present invention, as illustrate is Figure 6a, the process chamber **35** comprises a magnetic field source **195** that is adapted to provide or serve as means for maintaining a magnetic flux near or across the window **130**. When a substrate **30** held on the support **45** is processed by the energized process gas, the magnetic flux extending across a portion of the window **130** reduces the deposition of the process residues on the transparent plate **135** of the window. The magnetic field source **195** comprises at least one permanent magnet **200** or electromagnet (not shown) that is positioned adjacent to the window **130** to couple magnetic energy or flux across at least a portion of the surface of the window **130**. Preferably, the magnetic field lines are generally confined to the space around the window **130**, and penetrate only a shallow depth or not at all into the process chamber **35**.

A preferred magnetic field source **195** comprises a permanent magnet **200** arranged about the window to provide a magnetic field component that extends across a portion of the transparent plate **135** and in the plane of the window **130**. Preferably, the magnetic field source **195** provides a localized magnetic flux across the window **130** that has a higher density across the window than their density at other portions of the process chamber **35**, and that terminates at the edges of the window **130**.

The magnetic flux across the window **130** comprises magnetic field components that prevent charged process gas species from reaching the transparent plate **135**. For example, when the magnetic field lines or magnetic flux has a directional vector that is parallel to the plane of the window **130**, the field lines serve to confine charged plasma ions and electrons of the energized process gas to a circular path that is at a some fixed average distance away from the transparent plate **135** and thereby prevents deposition of process residues on the plate **135**. For example, a magnetic flux that extends across a portion of the window **130** and along a plane parallel to the window causes charged ions and electrons entering the region of the magnetic flux to rotate in a circular motion in this region. The magnetic field strength should be sufficiently high to confine the charged ions and electrons to the region of the magnetic field substantially without allowing the charged species to exit from this region. Generally, a suitable magnetic field strength is from about 10 to about 10,000 Gauss, and more preferably from about 50 to about 2000 Gauss.

In one embodiment, shown in Figures 6b through 6d, the magnetic field source **195** comprises a plurality of magnetic poles **205** disposed about a perimeter of the window **130**. The magnetic poles **205** around the perimeter of the window **130** comprise opposing magnetic polarities that are in facing relationship to one another. For example, as shown in Figure 6b, the magnetic field source **195** can comprise at least a pair of north and south poles **205a,b** that face one another. Preferably, the magnetic field source **195** comprises a magnetic yoke **210** (by which it is meant a ferromagnetic yoke of a permanent magnet or an electromagnet) having an aperture **215** therein. The magnetic yoke **210** provides a symmetrical magnetic field across the aperture **215**. Figure 6b shows an exemplary magnetic yoke **210** comprising at least a pair of radially extending poles **205a,b** that face one another and have opposing magnetic polarity. Alternatively, as shown in Figure 6d the magnetic yoke **210** can comprise a plurality of yokes of magnetic material that are arranged to

provide a plurality of radially opposing magnetic poles **205** facing one another across the aperture **215** to provide a magnetic flux across the surface of the window **130**.

The aperture **215** in the annular shaped or circumferentially disposed magnetic yoke **210** is sized to allow light to pass through the window **130**. The facing magnetic poles **205a,b** apply a magnetic field generally straight across the aperture **215** in the magnetic yoke **210**. The aperture **215** is sized sufficiently large to allow a sufficient intensity of light to pass through to operate the process monitoring system **25**. The total cross-sectional area of the aperture **215** is sufficiently large to allow a sufficiently large amount of light to ingress and egress from the process chamber **35** through the aperture **215**. The aperture can be cylindrical, triangulated, or rectangular in shape, of which a cylinder provides good axial symmetry for the magnetic field source and smooth internal surfaces.

Electrical Field Energizing

In another version, the process chamber **35** comprises a window **130** in a wall or the ceiling **55** of the process chamber **35** and an electrical field source **220** that couples electrical energy to the window **130**. The electrical energy coupled to the window **130** reduces the accumulation of the process residues on the window **130** by causing energized process gas ions to energetically bombard the window **130** and remove process residues deposited on the window. The electric field source **220** comprises an electrode **225** adjacent to the window. For example, as shown in Figure 7, the electrical field source **220** comprises an electrode **225** disposed adjacent to and behind the window **130** to induce a charge in the window and to generate an electric field perpendicular to the plane of the window **130** which causes energetic plasma ions and species in the process chamber **35** accelerate toward and impinge

upon on the window **130** to sputter-etch and remove the process residue deposits formed on the window.

In another version, shown in Figure 8a, the electric field source **220** comprises an electrode **225** having one or more apertures **230** therein, disposed between the transparent plate **135** and the light source **150** to provide an electric field that is perpendicular to the plane of the window **130**. The electrical field causes energetic plasma ions and species in the process chamber **35** accelerate toward the window **130**, pass through the aperture **230**, and impinge upon on the transparent plate **135** to sputter-etch and remove the process residue deposits. Preferably, the total cross-sectional area of the apertures **230** is sufficiently large to allow a sufficiently large amount of light flux to ingress and egress from the process chamber **35** through the aperture to operate the process monitoring system.

Additionally, eddy current reducing slots **232** are also sized, shaped, and disposed to reduce eddy currents induced in the electrode **225** by preventing a continuous pathway of current from being forming in the electrode. Eddy currents occur due to the electrical energy coupled from other process components, such as the inductor antenna **100**. The slots **232** reduce or eliminate the eddy currents by breaking up the circular pathway of the current in the electrode **225**. For example, as shown in Figure 8b, the electrode **225** can comprise a disc **235** having at least one radially extending cutout **240** that is in the pathway of the eddy current induced in the electrode **225**. Alternatively, as shown in Figures 8c and 8d, the electrode **225** comprises a series of radial wedge-shaped cuts **242** or an array of circular holes **243** spaced apart from one another.

As with the magnetic field source **195**, the electrical field source **220** is adapted to provide an electrical field or flux that extends across a portion

of or substantially the entire surface of the window **130**, and that terminates at or near the edges of the window **130**. More preferably, the electrode **225** is sized sufficiently large to provide an electric field that covers the entire area of the transparent plate **135** of the window **130** and is shaped and sized similar to the shape of the window **130**. A voltage source **245** electrically biases the electrode **225** with one of a D.C. voltage, an A.C. voltage, or an RF voltage. Alternatively, as shown in Figure 8a, the electrode **225** can be electrically biased by a tap **250** connecting a selected coil of the inductor antenna **100** to the electrode **225**. Thus the coil power supply **104** provides power to both the window electrode **225** and the inductor antenna **100**. Preferably, coil power supply **104** biases the electrode **225** with a voltage of from about 10 to about 10,000 volts, and more preferably from about 20 to about 4000 volts.

The mask **140** can also be used in combination with the magnetic and electrical field confinement methods. In this method, the mask **140** having the aperture **145** is aligned over the aperture **215** in the magnetic yoke **210** or over the aperture **230** in the electrode **225**, to align the aperture **145** to the apertures **210** or **230**. The aperture **145** of the mask **140** is shaped and sized to limit or reduce access of the energized process gas into the aperture **215** of the magnetic yoke **210** to prevent deposition of process gas byproducts and other deposits on the underlying transparent plate **135**. Alternatively, the aperture **145** is sized and shaped to screen out low energy plasma species and only allow highly energetic and directional plasma species into the aperture **145**. The highly energetic and directional species impinge upon sidewalls of the aperture **145** and upon the surface of the transparent plate **135** to sputter-etch and remove process gas deposits that are formed thereon.

The substrate **20** and process of the present invention allows accurate and reliable monitoring of the process being conducted in the process chamber **35** without excessive deposition of residues and deposits on the

window **130** for the process monitoring system **25**. The improved window **130** structure further reduces flaking of deposits from window components and thereby increases substrate yields. The window **130** is also much less susceptible to erosive damage from the plasma in the process chamber **35** than conventional windows **130**. By reducing the need to often replace the window **130**, the cost of operating the process chamber **35** and the cost per substrate **30** are also significantly reduced. Furthermore, the masked window **130** configuration allows use of the process chamber **35** over an extended period of time without stopping processing to wet clean the process chamber walls and components including the window **130**, thereby increasing etching throughput and further reducing costs per substrate **30**. The magnetic and electrical field confinement methods, can operate separately or in combination with the masking method, to reduce to entirely eliminate process residue deposition on the window.

The etching and endpoint detection method of the present invention significantly improve substrate yields by reducing etching or other damage of the thin gate oxide underlayer, during etching of an overlying polysilicon layer. In particular, the polysilicon etching process is stopped without etching through an ultra-thin gate oxide layer having a thickness of 25 to 65 angstroms, which is only a few layers of atoms of silicon dioxide, and which is 4 to 5 times thinner than prior art gate oxide layers. The etching method also minimizes the damage that a high density RF bias plasma can cause by the formation of damaging electrical currents that are coupled through the thin gate oxide layer into the silicon wafer. Also, by stopping the etching process before the thin gate oxide layer is damaged by the aggressive etching process step, the present process provides higher yields and better quality of integrated circuits.

Furthermore, the combination etching/cleaning process of the present invention has been found to uniformly etch substrates **30** while simultaneously removing etchant residues deposited on the process chamber **35** during the etching process, irrespective of the thickness or chemical stoichiometry of the etchant residue layers. Prior art etching processes required cleaning and conditioning of the process chamber **35** after processing of only 200 to 300 wafers, because of the variation in etching rates and etching selectivity ratio and the higher particle contamination levels that resulted from etchant residue deposits on the process chamber surfaces, after processing this number of wafers. Also, prior art cleaning processes, particularly those performed by an operator, often fail to uniformly clean and remove the etchant residue deposits formed on process chamber surfaces, and such build-up of etchant deposits resulted in flaking off and contamination of the substrate **30**.

The present invention is described with reference to certain preferred versions thereof; however, other versions are possible. For example, the treatment and cleaning process of the present invention can be used for treating process chambers **35** for other applications, as would be apparent to one of ordinary skill. For example, the process can be applied, as would be apparent to one of ordinary skill in the art, to treat sputtering chambers, ion implantation chambers, or deposition chambers, or in combination with other cleaning processes. Therefore, the spirit and scope of the appended claims should not be limited to the description of the preferred versions contained herein.